

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

QUANTITATIVE STUDIES ON INSHORE MARINE
DIATOMS AND DINOFLAGELLATES
OF SOUTHERN CALIFORNIA
IN 1921 AND IN 1922

BY

WINFRED EMORY ALLEN

BULLETIN OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY
LA JOLLA, CALIFORNIA

TECHNICAL SERIES, Volume 1, No. 2, pp. 19-29, 1 figure in text

Volume 1, No. 3, pp. 31-38, 2 figures in text

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA

1927

The SCRIPPS INSTITUTION OF OCEANOGRAPHY, LA JOLLA, CALIFORNIA, announces the beginning of a new series of its **Bulletin**—the **Technical Series**. The following numbers have been issued. Other numbers are in preparation.

Earlier papers from the Institution have appeared as **Bulletins of the Scripps Institution for Biological Research**, and as contributions to the series, **University of California Publications in Zoology**.

BULLETIN OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY,
TECHNICAL SERIES.—Edited by T. WAYLAND VAUGHAN and F. B.
SUMNER.

VOLUME 1. 1927—

1. Effect of Tidal Changes on Physical, Chemical, and Biological Conditions in the Sea Water of the San Diego Region, by Erik G. Moberg and Winfred Emory Allen. March, 192725
2. Quantitative Studies on Inshore Marine Diatoms and Dinoflagellates of Southern California in 1921, by Winfred Emory Allen.
3. *Idem*, 1922.
Nos. 2 and 3 in one cover. March, 192725
4. Surface Catches of Marine Diatoms and Dinoflagellates made by U.S.S. "Pioneer" in Alaskan Waters in 1923, by Winfred Emory Allen. March, 192725
5. Studies on Marine Diatoms and Dinoflagellates Caught with the Kofoid Bucket in 1923, by Henry P. Dorman. March, 192725
6. Notes on Cestodes and Trematodes of Marine Fishes of Southern California, by George F. Sleggs. March, 192725
7. Quantitative Studies on Marine Diatoms and Dinoflagellates at Four Inshore Stations on the Coast of California in 1923, by Henry P. Dorman.
8. Pelagic Fish Eggs off La Jolla, California, by P. S. Barnhart.
Nos. 7 and 8 in one cover. March, 192725
9. Marine Phytoplankton in the Region of La Jolla, California, during the Summer of 1924, by George F. Sleggs. March, 192730

PUBLISHED BY THE
UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA

1927

QUANTITATIVE STUDIES ON INSHORE MARINE
DIATOMS AND DINOFLAGELLATES
OF SOUTHERN CALIFORNIA
IN 1921

BY

WINFRED EMORY ALLEN

BULLETIN OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY
OF THE UNIVERSITY OF CALIFORNIA
LA JOLLA, CALIFORNIA

TECHNICAL SERIES, Volume 1, No. 2, pp. 19-29, 1 figure in text

Issued March 30, 1927

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA

CAMBRIDGE UNIVERSITY PRESS
LONDON, ENGLAND

QUANTITATIVE STUDIES ON INSHORE MARINE DIATOMS AND DINOFLAGELLATES OF SOUTHERN CALIFORNIA IN 1921*

BY
WINFRED EMORY ALLEN

CONTENTS

	PAGE
Introduction.....	19
Seasonal variations in numbers.....	20
Seasonal minima.....	23
Late summer minimum.....	24
Autumn minimum.....	25
Winter minimum.....	25
Effect of light.....	25
Variation in kind of organisms.....	26
Numbers at different levels.....	28
Conclusion.....	29
Literature cited.....	29

INTRODUCTION

In addition to continuing the collecting at La Jolla and Pt. Hueneme piers as in 1920, a similar series was begun at Oceanside in January, 1921, and some irregular collecting was done at Santa Barbara. The Oceanside pier is almost north of La Jolla, about twenty miles, in Lat. $33^{\circ} 10' N$ and Long. $115^{\circ} 20' W$. The Santa Barbara pier is about 155 miles northwest from La Jolla in Lat. $34^{\circ} 25' N$ and Long. $119^{\circ} 45' W$.

At all stations the dipping method (Allen, 1921) was used in collecting. Daily, except holidays, seven gallons of water were dipped from the surface with a pail and poured through a small conical filtration net of No. 25 bolting silk and the residue was preserved in formaldehyde. Methods of study (Allen, 1921) have remained the same throughout, the number of diatoms and of dino-flagellates to the liter being estimated from the results of counting a fractional part of each catch.

* This is the third of a series of reports dealing with this subject. For methods of collection and of study see Literature Cited, Allen, 1922*a* and *b*.

As stated in my report for 1920 (Allen, 1922b) our pier records are so voluminous that it has been found necessary in discussion to use time units larger than the day. For that reason the greater part of this report and of the one following deals with totals and averages for months or for seven-day periods (designated "weeks") in natural sequence from January 1.

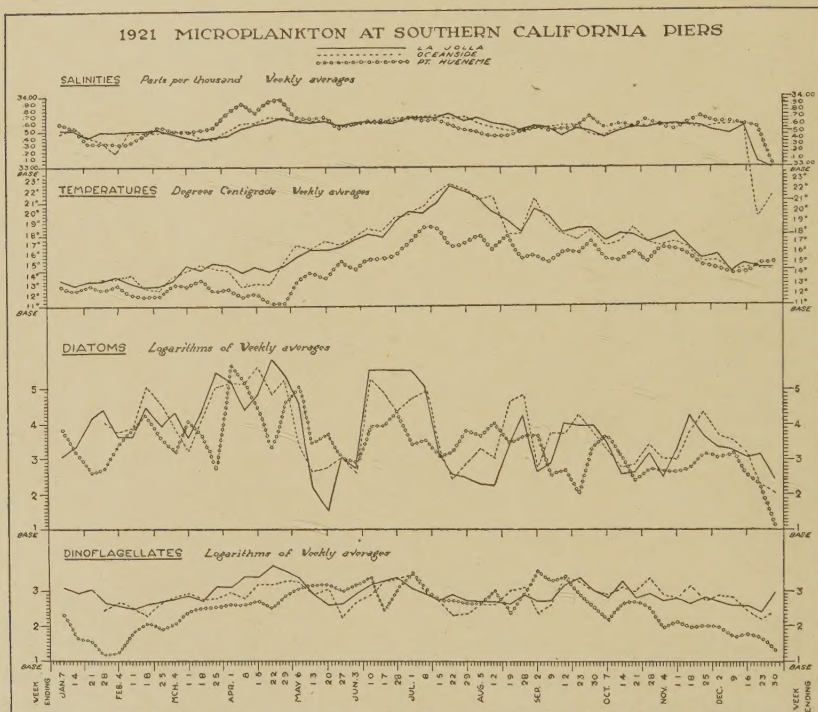


Fig. 1. Graphs to show logarithms of weekly averages of diatoms and dinoflagellates, with accompanying temperatures and salinities at southern California piers in 1921.

SEASONAL VARIATIONS IN NUMBERS

As compared with 1920 the seasonal changes in numbers were more nearly in accordance with the observations of various investigators in that there was a prominent vernal maximum followed by a decline in summer and a more or less distinct increase in autumn (fig. 1 and table 1). Oceanside showed a considerable increase in diatoms in February but the increase was more transitory than that at La Jolla in February of 1920. All three stations were alike in having very high production in April, the month which often brings

TABLE 1
AVERAGE NUMBERS OF CELLS PER LITER IN SUCCESSIVE SEVEN-DAY PERIODS
AT PIERS IN 1921

No. of week	Week ending	Diatoms			Dinoflagellates		
		La Jolla	Oceanside	Hueneme	La Jolla	Oceanside	Hueneme
1	Jan. 7	1114		6609	1146		179
2	14	2137		1381	795		40
3	21	13415		416	1047		35
4	28	27329	11016	504	432	253	13
5	Feb. 4	4286	6098	2496	343	430	16
6	11	4181	7918	7032	263	308	64
7	18	32009	118037	19762	368	179	111
8	25	9183	36151	3649	452	423	78
9	Mar. 4	22513	7734	1603	572	638	112
10	11	4229	1779	12586	639	803	251
11	18	25135	16667	4539	482	523	285
12	25	287778	117477	535	1271	531	303
13	Apr. 1	148961	147479	444073	1198	853	323
14	8	26320	143924	148292	2496	552	360
15	15	69374	438069	26867	2400	1550	472
16	22	746253	79083	2187	5179	1522	293
17	29	213531	195507	40667	3707	1863	690
18	May 6	36735	2713	123469	2235	1627	1168
19	13	135	402	2971	741	725	1267
20	20	39	571	4681	368	1096	1379
21	27	1097	1047	979	366	149	971
22	June 3	557	421	850	770	411	1343
23	10	334403	180503	8009	1367	695	2089
24	17	355673	86398	8931	1915	1737	253
25	24	334821	23169	24415	2181	2136	1128
26	July 1	329586	60590	2550	1090	2754	3184
27	8	124139	81499	3254	745	819	819
28	15	1449	1568	1227	501	418	408
29	22	347	254	1499	651	173	477
30	29	299	728	6688	559	189	381
31	Aug. 5	199	2009	4491	523	360	386
32	12	167	1058	10555	530	354	843
33	19	2800	48997	2751	382	985	224
34	26	18251	71749	4634	661	1214	789
35	Sept. 2	453	532	4551	402	200	3204
36	9	750	3373	333	464	375	1806
37	16	11073	5120	440	1349	2283	2404
38	23	9705	18203	112	2189	1627	677
39	30	9857	5941	2181	969	896	296
40	Oct. 7	2703	1763	5157	569	691	133
41	14	386	589	1087	1659	1200	387
42	21	411	688	232	536	955	427
43	28	1310	2518	525	766	2080	293
44	Nov. 4	315	1043	451	482	670	93

TABLE 1—(Continued)

No. of week	Week ending	Diatoms			Dinoflagellates		
		La Jolla	Oceanside	Hueneme	La Jolla	Oceanside	Hueneme
45	11	1915	998	426	523	560	115
46	18	18423	6010	624	393	1346	83
47	25	4582	23411	1443	574	494	99
48	Dec. 2	2206	4994	1149	417	650	83
49	9	1902	3760	1478	341	608	48
50	16	1225	1509	357	329	245	56
51	23	1467	197	172	210	144	41
52	30	286	107	13	839	240	16

maximum production of microplankton in both fresh and salt waters. According to reports of most observers of seasonal changes in plankton numbers, the decrease of extreme magnitude in May was less to be expected, so also were the abrupt increases of large magnitude at La Jolla and Oceanside in midsummer and again in late summer. But, except for their lesser magnitude, the moderate increases in September and October at La Jolla and Oceanside (fig. 1) are according to ordinary expectation.

No very large numbers of dinoflagellates were taken in any season and the most productive weeks had distinctly smaller average numbers than was the case in 1920. Such increases as did occur came at about the same time as those of the diatoms (fig. 1 and table 1). My own experience as well as the statements of other investigators (e.g., Herdman, 1922) indicate that marked increases of the two groups are likely to come at more or less distinctly different times in most years.

A really astonishing feature of seasonal distribution of diatoms at all three stations is the series of changes (fig. 1 and table 1) by which production became very low in May and then at two stations abruptly sprang to a great height which was fairly well sustained for five weeks through June to mid-July, when it descended with similar abruptness. A series of changes such as this occurred at La Jolla in midsummer of 1920, but that might have been explainable by narrowly localized conditions of some unrecognized character. In 1921 the influential conditions were obviously determinative over more than twenty miles of coast line and operative to a noticeable degree at the Pt. Hueneme station, more than one hundred miles from La Jolla. Unfortunately, information for comparison of conditions in other regions for the same period is not available.

SEASONAL MINIMA

An interesting feature of seasonal production at La Jolla, for which no adequate explanation is yet apparent, is that the minimum weekly average for the year was reached in June, 1920, and May, 1921, in the intervals between two highly productive periods (fig. 1 and table 1), but the difference in numbers between this spring minimum and the fall and winter minima is not significantly great. The greatest interest lies in its proximity to highly productive periods. Since there were distinct differences in relative prominence of component species in the two productive periods preceding and following this spring minimum the extreme decline was probably due to the whole set of changing conditions which forced out an old population and brought in a new one.

The decline in May is evidently in consonance with the well-known tendency of most populations to decline after periods of sustained productivity. Such a decline of population may usually be due to approaching exhaustion of food materials, to intolerable accumulation of wastes, to epidemics of disease, or to attacks by predatory organisms. Less frequently it may depend directly upon seasonal changes of weather or upon exceptional changes in the physical and chemical environment. In most cases it is surely caused by a combination of influences in which some of those first mentioned have prominent place. The interrelations and operations of such causes in decline of populations of land plants are becoming fairly well understood, but direct information concerning particular causes operating on marine microplankton is scanty or entirely lacking.

A change in numerical dominance in a population concurrently with a change in productivity harmonizes with the idea that exhaustion of food or accumulation of wastes may cause rapid decline in numbers of individuals, and such a change was noticeable at La Jolla in 1920 and at both La Jolla and Oceanside in 1921. In 1920 *Nitzschia seriata* Cl. held a distinct lead in productivity in February and March, which it regained in the June-July period after being eclipsed by *Chaetoceras debile* Cl. (including *C. curvisetum* Cl.) in May. In 1921 at both La Jolla and Oceanside *C. debile* Cl. (including *C. curvisetum* Cl.) led in the heavy production of April, but was not relatively prominent in June-July when *C. compressum* Laud. held the leading position. At Pt. Hueneme in 1921 the changes in these months were less pronounced and *C. debile* Cl. retained first place in productivity at both periods.

One might suppose that the unusually large amount of rain in May, 1921, contributed some influence toward lower production by disturbing general conditions of the sea water in the local area, but the showing at La Jolla in 1920, when there was no great amount of rain, renders such a view doubtful. In any case such influence as is exerted by the generally moderate rains of the La Jolla region is more likely to be through diffusion of new substances from the land than through physical effects of changes in salinity. There is also a possibility that changes in movements of the mass of ocean water accompanying stormy weather might scatter a dense population localized inshore or might sweep it into entirely new territories. As a matter of fact such movements on a small scale are sometimes observable from the Scripps Institution pier.

LATE SUMMER MINIMUM

The decline to a minimum in late summer is a phenomenon so noticeable, not only in these catches but in those of series taken in other parts of the world, that it seems fairly safe to say that it is somehow connected with the influence of the maximum temperatures usually appearing about that time.

While records of the Scripps Institution clearly show that several of the most prominent species of diatoms are to be found in surface catches widely different in temperature, it is possible that the population of a given locality at any certain time may be tolerant of much less difference than appears to be tolerable for the species in general. It is well known that at times of unusually high temperature of the surface water the kelps of southern California suffer severely from 'scalding,' losing those fronds which occupy the upper layers. And, since large diatom populations are sometimes found at depths of thirty to seventy meters in late summer (as shown by unpublished records of the Scripps Institution) at times of surface decline in production, it may be supposed that rise in temperature above a certain limit is injurious or even fatal to them. Since other explanations of this condition in late summer might be offered it should not be assumed that temperature is solely responsible although it does seem probable that the effects of temperature can be more definitely traced at this than at any other season (fig. 1).

AUTUMN MINIMUM

The lack of a prominent pulse of production at all three stations in 1921 is rather unexpected in consideration of the heavy pulse in September, 1919 (Allen, 1922*a*) and the moderate pulse in September, 1920 (Allen, 1922*b*) at La Jolla. There are no recorded observations of such factors as temperature and salinity (fig. 1), which even suggest a possibility of an explanation from the standpoint of physical conditions of the environment. My opinion is that production is rarely determined by any one factor or small group of factors. In this case the physical and chemical factors may have been favorable but one or more biological factors may have been unfavorable. A very good explanation, which might be a true one, is that not enough 'seed' diatoms were present in the area at the time most favorable for starting a pulse. We have no information on that point but it is only one of many possibilities which may at any time upset calculations of probabilities. While, under the stress of human limitations, studies must be confined to a few conspicuous factors in any problem of natural relationships, it should be borne in mind that some obscure or unrecognized factor may be determinative.

WINTER MINIMUM

The extreme reduction of salinity in December, due to the winter rains, showed most influence at Pt. Hueneme and Oceanside, those collecting stations being nearer than La Jolla to the outlets of streams. In this case it is probable that lower salinity was mainly responsible for almost complete suppression of the marine microplankton.

EFFECT OF LIGHT

In the twelve years of my special attention to plankton problems I have been much interested in all discernible evidences of influence of light. Like other students of plankton I have assumed that light has a profound influence on increase and decrease of plankton populations, but direct evidence as to the character and extent of that influence is so scanty and so difficult to identify among the evidences of many other powerful influences that I have been able to do scarcely more than make the assumption. However, for the sake of record

rather than for the sake of recognized significance, I note herewith that San Diego records (table 2) of the U. S. Weather Bureau giving percentage of sunlight for 1919 to 1921, inclusive, do not accord with the usual assumption that vernal (or early annual) increases of phytoplankton are governed by the amount of sunlight.

TABLE 2
PERCENTAGE OF SUNLIGHT AT SAN DIEGO

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1919	75%	73%	69%					
1920	82	78	72	49%	46%	65%	73%	50%
1921				67	73	68	81	49

As shown by table 2, the percentage of sunshine in every month from October, 1919, to April, 1920, inclusive, was less than that for the same interval in 1920 and 1921. From such a condition one would expect diatom increases to begin earlier in 1921 than in 1920 and to be consistently heavier. The contrary was true at La Jolla (cf. Allen, 1922*b*), where some of the heaviest production of 1920 occurred in February, the number of productive weeks was greater than in 1921, and the total production was greater than in 1921. This set of records furnishes a good example of the futility of trying to say that any *one* of a multitude of conditions must necessarily be determinative in a single series of biological phenomena.

VARIATION IN KIND OF ORGANISMS

As in 1920 (Allen, 1922*b*), so in 1921, there is no very positive evidence of changes in species present in the population in connection with changes of season, i.e., we have no records to show that absence of species at certain times may not have been due to the relatively small size of the sample. Who can say that filtration of a thousand cubic meters of water instead of one forty-thousandth of that amount might not have shown representatives of the full list of species? However, more species were present in the productive period of April than in that of June-July, although the more common forms were found at both times. This indicates that some are either intolerant of summer conditions or else that they are not able to maintain themselves among those most thriving at that time. It may be true that some are favored by summer conditions in such a way that they are able to crowd out many competitors present at the earlier period. The well-known successional behavior of land plants, and my own

general observations, lead me to think that more species are present at the earlier period because the general environment is then more variable in character and therefore favorable to more kinds of organisms.

At La Jolla in 1921 there were only ten weeks in which diatom production might be said to be good (table 1). These ten weeks were in three periods; first, the two weeks ending on April 1; second, the three weeks ending on April 29; and third, the five weeks ending on July 8. In all three periods the catch-all assemblage of small (or otherwise poorly marked) forms called *Chaetoceras* sp. was second in numerical prominence. *Chaetoceras scolopendra* Cl. was most numerous in the first, and third in the other two periods, *C. debile* Cl. (including because of imperfect separation *C. curvisetum* Cl.) was third in the first period and first in the second, and *C. compressum* Laud. was first in the third period. No other species approached these in prominence in these periods, but *Nitzschia seriata* Cl. and *Eucampia zodiacus* Ehr. were present in notable numbers at various times.

At Oceanside there were thirteen weeks in which the average production of diatoms was approximately 50,000 cells to the liter or more (table 1). These thirteen weeks were distributed in five periods, the first being one week ending February 18, the second including six weeks ending April 29, the third including two weeks ending June 17, the fourth including two weeks ending July 8, and the fifth including two weeks ending August 26. In the first of these periods *Skeletonema costatum* Grev. was most numerous, but it was not one of the three most abundant species at any of the other four periods. *Chaetoceras debile* Cl. (including *C. curvisetum* Cl.) was second in the first period and first in the second, but not among the first three in the three remaining periods. *Chaetoceras* sp. was third in the first period, second in the next two, and first in the last two. Since the components of this group were not separated in any of these periods it is impossible to say how great differences appeared in this catch-all assemblage at the various seasons, but they were doubtless considerable. *Nitzschia seriata* Cl. was third in the second and fifth periods but less than third in the other three. *Chaetoceras compressum* Laud. came into first place in the third period and dropped to second in the fourth. It was not among the first three at the other periods so far as the records show. It ought, however, to be carefully noted that this species is often so difficult to separate with certainty that it is likely to be a prominent component of "*Chaetoceras* sp." and that it therefore deserves some credit for the showing of that indefinite group. Other species appearing in the list of three most numerous at these periods were *Chaetoceras scolopendra* Cl.

(third in the third period), *Eucampia zoodiacus* Ehr. (third in the fourth period), and *Chaetoceras sociale* Laud. (second in the fifth period). These seven were the only species which attained notable prominence at Oceanside at any season in 1921. Their periods of prominence show slightly more evidence of seasonal change than was recorded at La Jolla, e.g., *Skeletonema costatum* (Grev.) seems to be favored by winter conditions, *Chaetoceras debile* Cl. by spring, and *C. compressum* Laud. and *C. sociale* Laud. by summer.

At Pt. Hueneme there were only two periods in which the weekly average of diatom production approached or exceeded 50,000 cells to the liter (table 1). The first was the two weeks ending April 8 and the second was the two weeks ending May 6. In addition to *Chaetoceras* sp. three species attained notable prominence in these two periods. *Chaetoceras debile* Cl. (including *C. curvisetum* Cl.) was first in the first period and second in the other, *Chaetoceras* sp. was second in the first and third in the other, *C. scolopendra* Cl. was third in the first, and *Skeletonema costatum* (Grev.) was first in the second. *Nitzschia seriata* Cl. was the only other species which made a prominent showing at Pt. Hueneme. At this station *Chaetoceras debile* Cl. reached particular prominence earlier than any other species, a fact which casts some doubt on any supposition that a seasonal sequence is shown by its time of appearance at Oceanside.

At all three piers the numbers of dinoflagellates in 1921 were too small to give a good basis for interpretation of environmental influences. In only one case did the average number to the liter for a week reach five thousand. On this account dinoflagellates will not be discussed in this paper. *Prorocentrum micans* Ehr. was the most prominent species at all three piers.

NUMBERS AT DIFFERENT LEVELS

Early in 1921 Mr. F. W. Wood, a friend of the Scripps Institution, devised, manufactured, and donated a small (two and one-half gallons capacity) but effective closing bucket for use on the pier. Its operation was found rather difficult, however, and it was used for comparative collecting only nine times under good conditions. Four comparison catches were made in March and five in April. On these occasions the standard collecting by dipping was done at the surface and the closing bucket was used for collecting near the bottom at about eighteen feet below the surface. In all of these cases there was not more than a half-hour of difference in time of collecting at the surface and at the bottom.

Of the nine pairs of catches six showed larger numbers of diatoms at the lower level and three showed slightly larger numbers at the surface. The five pairs of catches in April were made on three successive days in a productive period and in every case the bottom catch was much the larger. Although the amount of evidence afforded by these catches is small it is clear that at some times there may be enormous differences in the density of population at slightly different levels, even at points so close inshore that we might expect a good deal of mixing action from ground swells and currents.

CONCLUSION

The conclusions stated for 1920 are supported by the records for 1921. In addition the following may be noted:

1. That certain species tend to hold prominent places in the populations in successive years.

2. That the periods of heavy production of diatoms may differ widely as to times of appearance in successive years and that their duration and magnitude may also be greatly different.

3. That the remarkable similarity of showing of seasonal changes (fig. 1 and table 1) in productivity in three distinctly different geographic areas indicates the operation of influences coincidentally effective over extensive territory.

4. That there may be great quantitative and qualitative differences in population at slightly different levels.

5. That recognition of *single* causes of changes in population is not to be expected on the basis of present information although such recognition may at any time become possible for some particular factor.

LITERATURE CITED

ALLEN, W. E.

- 1921. Some work on marine phytoplankton in 1919. *Trans. Am. Micr. Soc.*, 40: 177-181.
- 1922a. Quantitative studies on marine phytoplankton at La Jolla in 1919. *Univ. Calif. Publ. Zool.*, 22: 329-347.
- 1922b. Quantitative studies on inshore marine diatoms and dinoflagellates of Southern California in 1920. *Univ. Calif. Publ. Zool.*, 22: 369-381.

HERDMAN, W. A.

- 1922. Some results of plankton investigations in the Irish Sea. *Spolia Runiana V. Extr. Linn. Soc. Jour. Bot.*, 46: 141-170.

U. S. WEATHER BUREAU.

- 1921. Report of the Chief of the Weather Bureau, pp. 58-59.
- 1922. *Ibid.*, pp. 54-55.
- 1923. *Ibid.*, pp. 66-67.

QUANTITATIVE STUDIES ON INSHORE MARINE
DIATOMS AND DINOFLAGELLATES
OF SOUTHERN CALIFORNIA
IN 1922

BY

WINFRED EMORY ALLEN

BULLETIN OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY
OF THE UNIVERSITY OF CALIFORNIA

TECHNICAL SERIES, Volume I, No. 3, pp. 31-38, 2 figures in text

Issued March 30, 1927

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA

CAMBRIDGE UNIVERSITY PRESS
LONDON, ENGLAND

QUANTITATIVE STUDIES ON INSHORE MARINE DIATOMS AND DINOFLAGELLATES OF SOUTHERN CALIFORNIA, 1922*

BY
WINFRED EMORY ALLEN

CONTENTS

	PAGE
Introduction.....	31
Seasonal variations in numbers.....	34
Prominent species.....	36
Temperature.....	37
Summary.....	38
Literature cited.....	38

INTRODUCTION

Collections were taken daily (except Sunday) throughout the year at three pier stations (see fig. 1), Scripps Institution, Oceanside, and Pt. Hueneme. Collections were also taken at the pier of the U. S. Kelp Experiment Station at Santa Barbara in the first half of the year.

Catches at the Scripps Institution pier were uniformly made at about 7:15 A.M. At the other stations they were usually made a little later in the forenoon, and the times were more variable.

Most of these weekly averages (see table 1) have been computed from the daily records of individual catches, but for the last four months of 1922, at Pt. Hueneme, the averages have been obtained volumetrically by mixing uniform fractional parts of the individual catches for a given week and then making a single numerical study of that mixture for the week—a method suggested by Director T. Wayland Vaughan. This method appears to answer the purposes of general study as well as the other and it avoids an enormous amount of work, both microscopic and clerical. Where applicable, it is to be used as a standard method for the more general studies at our Institution in the future.

* This is the fourth of a series of reports dealing with this subject. For methods of collection and of study, see Literature Cited, Allen, 1922*a* and *b*.



Fig. 1. Marine Coastal Region of Southern California.

TABLE 1

AVERAGE NUMBERS OF CELLS PER LITER IN SUCCESSIVE SEVEN-DAY PERIODS
AT PIERS IN 1922

No. of week	Week ending	Diatoms			Dinoflagellates		
		La Jolla	Oceanside	Hueneme	La Jolla	Oceanside	Hueneme
1	Jan. 7	103	1880	25	633	1380	16
2	14	660	40	298	409	40	19
3	21	957	796	2162	427	40	37
4	28	9028	5150	9954	450	53	48
5	Feb. 4	36066	1540	1449	285	10	52
6	11	13670	2672	2707	377	15	24
7	18	3527	183	4573	397	18	28
8	25	29519	2187	3269	311	50	160
9	Mar. 4	21824	1918	428	455	123	0
10	11	21079	4803	2132	950	397	32
11	18	23960	5550	1848	644	440	32
12	25	1113	13212	7507	1097	1506	368
13	Apr. 1	368	1277	3658	800	2045	400
14	8	1211	558		2196	3684	
15	15	2555	5205	83304	7339	907	314
16	22	837365	768134	109628	3670	2585	2217
17	29	497944	8738	16068	6799	11604	288
18	May 6	1375	517	4112	2288	33557	848
19	13	6721	600	6504	1064	2760	117
20	20	22700	2416	262	3393	13912	115
21	27	20992	1833	212608	14226	32297	489
22	June 3	898	84	8318	3667	8860	381
23	10	1385	300	2794	711	1177	587
24	17	21206	1400	12860	2891	20415	341
25	24	76330	28816	3120	3675	7128	314
26	July 1	258	1727	456	839	387	309
27	8	379	805	13120	843	490	2459
28	15	5873	558	5184	775	345	4162
29	22	52	1092	63112	306	208	18431
30	29	4453		126787	423		6877
31	Aug. 5	3344	705	145208	607	117	9259
32	12	34	753	29977	274	165	2590
33	19	132	270	7200	443	368	2752
34	26	30	204	1696	516	760	2976
35	Sept. 2	39	152	3100	583	403	1824
36	9	187	40	2976	657	70	3872
37	16	635	435	2880	888	422	3616
38	23	325	142	7744	1040	227	5200
39	30	11165	320	1312	617	132	5648
40	Oct. 7	1408	1604	27936	608	340	11136
41	14	1865	10605	14096	503	327	53526
42	21	866	2060	12576	1136	205	20240
43	28	427	690	1376	1377	42	2560
44	Nov. 4	15438	500	15744	2290	370	2272

TABLE 1—(Continued)

No. of week	Week ending	Diatoms			Dinoflagellates		
		La Jolla	Oceanside	Hueneme	La Jolla	Oceanside	Hueneme
45	11	117709	23964	14912	692	1565	1184
46	18	236244	127300	7328	1376	3600	704
47	25	2553	16035	1472	1042	2493	672
48	Dec. 2	283	274	1984	569	144	608
49	9	73	105	448	832	78	96
50	16	50	117	736	503	130	160
51	23	43	157	576	600	348	128
52	30	203	245	320	532	260	320

SEASONAL VARIATIONS IN NUMBERS

The general impression given by the records for 1922 is that productivity was not good and that it was rather unstable (table 1 and fig. 2). At La Jolla and Pt. Hueneme there were only four weeks, and at Oceanside only two weeks, in which average production was greater than 100,000 diatom cells to the liter. At both La Jolla and Oceanside for many weeks the average was below 1,000 diatom cells to the liter. The showing for dinoflagellates is still lower, but is not so greatly different from the preceding years.

Although there was an April maximum at both La Jolla and Oceanside piers, it was of short duration and was not remarkably greater than the unusual pulse in November (table 1 and fig. 2). The low production at La Jolla and Oceanside in July and August extended over several weeks and constitutes the most stable period of the year. At Pt. Hueneme the waves of diatom production were later and not so low as at the other two localities.

Perhaps the most striking feature for the year is the strong wave of production of diatoms at La Jolla and Oceanside in November (table 1 and fig. 2). The sunshine records of the U. S. Weather Bureau for San Diego indicate over 10 per cent more sunshine for November, 1922, than for that month in any one of the three years preceding, and this may be a leading cause of the unusually strong wave of production at La Jolla. Whatever causes were responsible for it, produced some effect also at Pt. Hueneme.

Another striking feature for the year is the difference in seasons of productivity between Pt. Hueneme and the other two stations. In preceding years, notwithstanding differences in details, there had been a general resemblance. In 1922 Pt. Hueneme produced about

the same numbers of diatoms in the first and second half-years and more dinoflagellates in the second half than in the first. On the contrary, La Jolla and Oceanside, as in preceding years, showed more production in the first half-year (table 1 and fig. 2). It is true that Pt. Hueneme showed a strong pulse of diatoms in July which might

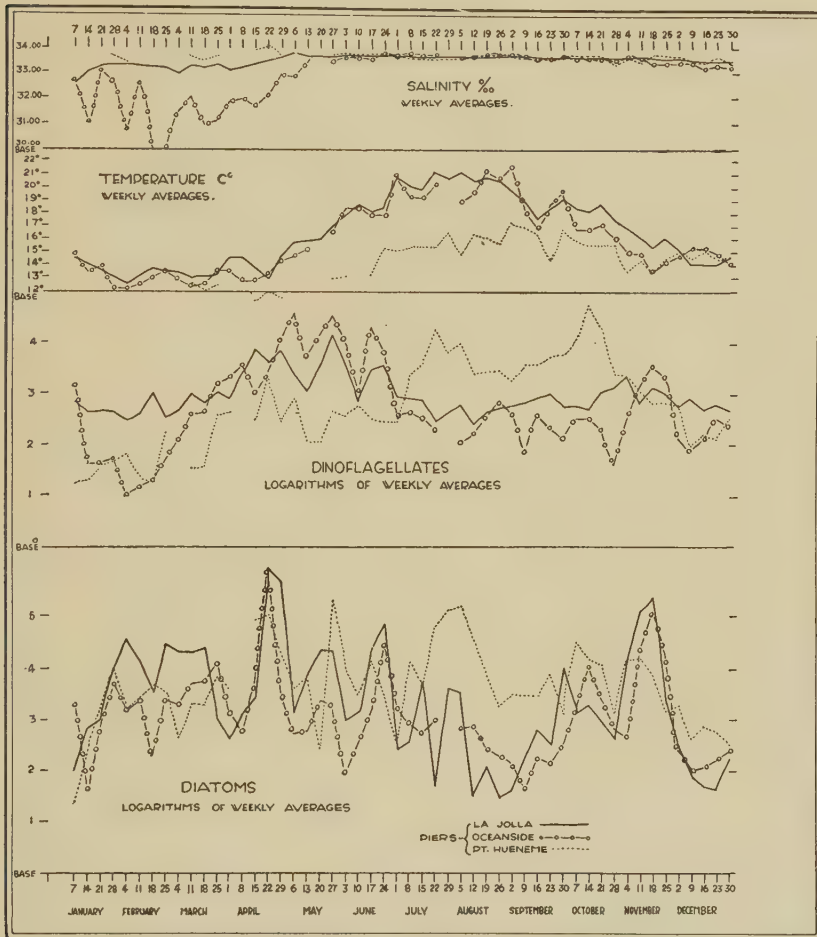


Fig. 2. Graphs to show logarithms of weekly averages of diatoms and dinoflagellates, with accompanying temperatures and salinities, at southern California piers in 1922.

be considered as merely an unusual lag behind the other two stations, or behind production of preceding years, but it is just as difficult to explain such a lag (see under "Temperature" below) as it is to explain the heavier total production for the second half-year. In preceding years the differences in quantities produced and in their

periods of production have not been so great as might be expected from the location of Pt. Hueneme on the Santa Barbara Channel and of the other two stations on the shore of the Gulf of Santa Catalina (see fig. 1). Such a difference as this gives positive evidence of the possibility of occurrence of marked differences in environmental control of productivity in the two regions in any season or any year.

In 1920, dinoflagellate production for the year as a whole was slightly greater at Pt. Hueneme than it was at La Jolla. In 1921 production at La Jolla was considerably greater than that at either Oceanside or Pt. Hueneme. In 1922, the total for the year was about the same at Oceanside as at Pt. Hueneme, coming mostly in the first half-year at the former location and in the second half-year at the latter. Total production at La Jolla was only about half that of either of the others, but it resembled production at Oceanside in period of prominence.

PROMINENT SPECIES

Little effort has been made to separate poorly marked and numerically unimportant species of either diatoms or dinoflagellates in this material. Early in the work of the first year it became evident that efforts at complete identification consumed an amount of time beyond reasonable proportion to the possible advantages of having such detail in the statistical records. It has therefore become a settled plan to use approximate identifications for the more obscure forms. For that reason there is no particular value in comparing the total number of species recorded for the different piers.

A general survey of the detailed records shows that in 1922 ten species of diatoms were noticeably more abundant than others at some time in the year. Four of these, *Chaetoceras compressum* Laud., *C. debile* Cl., *C. scolopendra* Cl., and *Nitzschia seriata* Cl. were noticeably abundant at all three stations; two, *Asterionella japonica* Cl. and *Chaetoceras sociale* Laud. at La Jolla and Pt. Hueneme; one, *Eucampia zoodiacus* Ehr., at La Jolla and Oceanside; one, *Thalassiosira decipiens* (Grun.) at Oceanside and Pt. Hueneme; and two, *Leptocylindrus danicus* Cl. and *Skeletonema costatum* (Grev.) at Pt. Hueneme only. Several other species appeared in fairly large numbers at one or more of the more productive periods but they were obscured by the more prolific leaders. In the geographic distribution of the leading producers for 1922 two points deserve particular notice; viz., *Eucampia zoodiacus* Ehr. is not prominent at the northern station, and the genus *Thalassiosira* is not prominent at the southern station. This, together with some evidence available from

other series, indicates a restriction of productive range which may have some value in further studies of geographic distribution. The lack of prominence of *Skeletonema costatum* (Grev.) at either La Jolla or Oceanside is also of special interest since that species usually reaches a prominent position in those localities at one or more periods of the year.

In the matter of seasonal distribution it is notable that the four species which attained prominence at all three stations showed ability to do so at almost any season of the year. *Chaetoceras debile* Cl. was prominent in February, March, April, and November at La Jolla; in February, April, June, and November at Oceanside; and in February, April, May, July, and November at Pt. Hueneme. *C. compressum* Laud., *C. scolopendra* Cl., and *Nitzschia seriata* Cl. showed similar tendencies at La Jolla and Oceanside, but at Pt. Hueneme they were prominent only in May and July. *Eucampia zoodiacus* Ehr. is another species which retained prominence through much of the year at the two stations which seemed more favorable for it. Other species were more limited.

Two species of dinoflagellates, *Ceratium tripos* (O. F. M.) and *Prorocentrum micans* Ehr. were prominent at all three stations; three, *Ceratium furca* (Ehr.), *Dinophysis caudata* Kent, and *Peridinium divergens* Ehr. at La Jolla and Oceanside; while one, *Noctiluca scintillans* (Macartney) became notable only at Pt. Hueneme. *Ceratium tripos* (O. F. M.) held place among the leaders at La Jolla and Oceanside through most of the year, but only in June at Pt. Hueneme. *Prorocentrum micans* Ehr. came into prominence at La Jolla and Oceanside in June and at Pt. Hueneme in July, after which it held a prominent position. The heavier production of dinoflagellates at Pt. Hueneme after midsummer is to be credited mainly to this species.

TEMPERATURE

For the year 1922 there seems to be some traceable connection between changes in temperature and the major shifts in production (fig. 2). Although much broken there is a discernible period of productivity of diatoms, mid-April to late June, just preceding the high levels of temperature. The lower temperatures at Pt. Hueneme run a course nearly parallel with the others, and there the productivity of diatoms became best just before the high temperatures were reached, but the time was extended to August, a month later than at the other stations. The dinoflagellate production showed somewhat similar characteristics.

SUMMARY

1. This is the third year in which the numbers of dinoflagellates in surface catches were very much less than those of diatoms, although production was not well sustained in either group.

2. The nearly equal production of diatoms in the two halves of the year at Pt. Hueneme and the heavier production of dinoflagellates in the second half-year is interesting because of contrast with heavier production in the first half-year at La Jolla and Oceanside (table 1).

3. The strong pulse of production at La Jolla and Oceanside in November (table 1 and fig. 2) shows definitely that regional conditions may sometimes change abruptly and encourage productivity at a season usually regarded as unfavorable.

4. In the region of southern California, as a whole, the same species of diatoms and dinoflagellates as in preceding years showed tendencies to leadership in production.

5. Certain species tend to leadership in production at all stations and all seasons.

6. Some direct influence of temperature and salinity seems to be traceable in 1922.

7. There is some indication that an unusual amount of sunlight in November was a leading cause of the unusual production of diatoms at that time.

LITERATURE CITED

ALLEN, W. E.

1922a. Quantitative studies on marine phytoplankton at La Jolla in 1919. Univ. Calif. Publ. Zool., 22: 329-347.

1922b. Quantitative studies on inshore marine diatoms and dinoflagellates of Southern California in 1920. Univ. Calif. Publ. Zool., 22: 369-381.

U. S. WEATHER BUREAU.

1919-20. Report of the Chief of the Weather Bureau, p. 59.

1920-21. *Ibid.*, p. 55.

1921-22. *Ibid.*, p. 67.

1922-23. *Ibid.*, p. 61.

